Emerging issue of e-waste in Pakistan: A review of status, research needs and data gaps

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Abstract

This review article focuses on the current situation of e-waste in Pakistan with the emphasis on defining the major e-waste recycling sites, current and future domestic generation of e-waste, hidden flows or import of e-waste and discusses various challenges for e-waste management. Needed policy interventions and possible measures to be taken at governmental level are discussed to avoid the increasing problem of e-waste in the country. Our findings highlight that there is still a general lack of reliable data, inventories and research studies addressing e-waste related issues in the context of environmental and human health in Pakistan. There is therefore a critical need to improve the current knowledge base, which should build upon the research experience from other countries which have experienced similar situations in the past. Further research into these issues

in Pakistan is considered vital to help inform future policies/control strategies as already successfully implemented in other countries.

Key words: E-waste, illegal import, recycling sites, status, research needs, data gaps, management, Pakistan

***Capsule*:**

We present a baseline study on e-waste in Pakistan which could guide or facilitate more detailed studies in the future and ultimately lead to improve control strategies.

1. Introduction

Electronic and/or electrical waste (e-waste) is a growing problem all over the world. There is no exact definition of e-waste but according to the Organization for Economic Co-operation and Development (OECD) "any appliance using an electric power supply that has reached its end-of-life" is termed as an e-waste. Another term which is also used along with e-waste is waste electrical and electronic equipment (WEEE) which includes non-electronic items like ovens and refrigerators, but the distinction between both is becoming blurred due to advent of pervasive computing[1]. According to the Directive 2002/96/EC of the European Parliament and of the Council (January 2003) on Waste Electrical and Electronic Equipment (WEEE), ten categories of e-waste are defined[2]. Out of all these ten categories, categories 1-4 contribute with 95% of the amount of e-waste generated worldwide (Table S1). In general, home appliances represent the major fraction of e-waste produced worldwide by weight; it contributes approximately 50% with communication, information equipment with 30% and consumer appliances with 10%[3]. E-waste is chemically and physically distinct from other types of industrial and municipal waste and includes both valuable metals like copper and gold as well as various hazardous substances (flame retardants, lead, mercury, arsenic, etc.)[4], which requires special handling and recycling techniques to minimize

environmental contamination and potential harmful effects on human health. A combination of shorter life span of appliances, increased consumption, low recycling rates, and illegal transboundary transport of e-waste from developed to developing countries[5] are all driving forces which contribute to elevated exposures to toxic substances in some developing regions. High labor costs, strict environmental regulations and lacking facilities for recycling of e-waste make developed and rich countries prone to export some of their e-waste to poor and developing countries. E-waste in poor and developing countries is often treated and recycled at the expense of environment and human health[6].

United Nations (UN) reported that the world's generation of e-waste in 2006 was 20-50 million tons per year, which accounts for 1-3% of total municipal waste produced worldwide[7]. A more recent update projected that the global e-waste generation will increase from 48.9 million tons in 2012 up to 65.4 million tons per annum in 2017[8]. By the year 2030, it is forecasted that developing countries will discard twice as much e-waste as developed countries[9].

Activities related to informal recycling and improper disposal of e-waste can release persistent toxic substances (PTSs) into environment and thus into food webs[10]. Worldwide attention has been drawn towards the adverse and negative effects of PTSs on the environment including human health. Several PTSs are known to be endocrine disrupters, posing adverse health effects such as reproductive disorders, developmental deformities, and cancer in both humans and wildlife[10] (Table S2). Various studies have been carried out on possible negative impacts of e-waste recycling and disposal in developing regions with many discussing the situation in Southeast Asia. Wong et al.,[11] carried out a study in Guiyu, China in which the authors determined the levels of flame retardants, polycyclic aromatic hydrocarbon (PAHs), polychlorinated biphenyl's (PCBs) and heavy metals in air, soil and sediment in surroundings of e-waste recycling facilities[11].

Similarly, Leung et al.,[12] Deng et al.,[13] Bi et al.,[14] Wang et al.,[15] have reported high levels of flame retardants, PCBs and Organochlorines (OCs) in Guiyu city, which is considered among the major e-waste recycling site of the world[16]. Fewer studies have been carried out in India addressing the impacts of e-waste recycling on environment[17,18,19]. Yet, all these studies have focused on negative impacts of e-waste recycling and imports which have attracted increased attention to the need for improved management strategies in these countries. In contrast, the situation in Pakistan largely remains to be addressed. The unsafe and environmentally damaging practices used for recycling of e-waste represent an increasing challenge for Pakistan with no registered recycling facilities. The issue to this point has received very little attention from governmental and non-governmental organizations in Pakistan. To date no scientific study has been made to assess the impact of e-waste processing to environment of Pakistan. There is no reliable data available on the volume of used electronic components imported and the fraction of it recycled or dumped as solid waste.

The main objective of this study is to review the current situation of e-waste in Pakistan. As Pakistan receives imports of e-waste from abroad, we first briefly discuss the generation and hidden flows of e-waste on a global scale to provide context for this work. This is followed by an analysis of the amounts of e-waste generated and manufactured within Pakistan, including scenarios for the future. We then explore the major flows and destinations of e-waste within Pakistan, followed by a discussion of domestic regulations and regulatory needs to improve the situation in terms of protecting environmental and human health. We close the manuscript by discussing the more critical data gaps and research needs. Our hope is that this study will serve as a baseline study on e-waste in Pakistan which could guide or facilitate more detailed studies in the future and ultimately lead to improve control strategies to better protect environmental and human health.

2. E-waste in a global context

2.1. Global generation and flows of e-waste

There have been several studies estimating the global generation of e-waste. A recent report by UNU (United Nations University) revealed quantities of e-waste generated in 2014, which is 41800 kt and is forecasted to increase to 50000 kt in 2018[20]. According to Step, total generation of e-waste worldwide was 48894 kt[21] in 2012. Robinson et al. [22]estimated that 20000-25000 kt e-waste was generated annually in 2005, while Breivik et al. [23] suggested the annual generation to be ~35000 kt in the same year, which represents the average of estimates made by UNEP (2006). We can assume that the current and future e-waste generation would be at the higher end of historical estimates because of an increase in the global generation of e-waste in time[23,22].

Despite the existence Basel Convention on the control of transboundary movements of hazardous wastes and their disposal and other conventions, the transfer of e-waste from the United States, Canada, Australia, EU, Japan and Korea to Asian countries such as China, India and Pakistan remains relatively high[24,25,26,27]. Figure 1 depicts the flow of e-waste entering into major countries in Asia i.e.; China, India and Pakistan. E-waste imported to China is reported to come from US, EU, Japan, South Korea and several other countries of the world[28,24], and it has been claimed that 60-75% of e-waste collected in EU is sent to Asian and African countries for recycling or dismantling[29] . E-waste in Pakistan is allegedly imported from US, EU, Australia, Saudi Arabia, Kuwait, Singapore and UAE among many other countries[26, 30]. Dubai in UAE and Singapore supposedly also serves as pre-distribution centres of e-waste coming from EU and US to South Asian countries with India and Pakistan as the major destinations[27].

When the e-waste escapes from formal collection and management, it is then handled illegally, referred to as the “Hidden Flow of e-waste”[24]. The associated export of e-waste from developed

to developing regions has been ongoing for years. Because of the illicit character of such exports, there is still very limited information available on the transboundary movement of e-waste from developed regions and estimates of hidden flows are typically highly variable. This also applies to the European countries, which have very strict rules and regulations. Out of all the e-waste generated in EU, it has been suggested that only 25% of it is collected and treated while 75% is generally the "hidden flow" of EU[27]. The hidden flow was more recently evaluated by Breivik et al.,[23], in which they estimated that 23% (17%-34%) of the total e-waste generated within OECD countries (Organization for Economic Co-operation and Development) was imported to non-OECD countries in 2005[23]. That study also summarized data on the large amounts of e-waste imported to just seven non-OECD countries (China, India and five West African countries). The authors emphasized that there are other non-OECD countries (including Pakistan) implicated as importers, but which remain to be accounted for[23].

Table 1 presents earlier estimates of the global generation of e-waste along with data for major Asian countries. In order to update the estimates to reflect the recent situation, we performed a simple calculation by multiplying the amount of e-waste generated per capita in 2012 with the population of 2014. From Table 1, it can be seen that the estimated domestic generation of e-waste in Pakistan (315 kt) is far less than India and China, reflecting a combination of lower population and purchasing power in Pakistan, compared to India and China. Table 1 reveals that India generated approximately 2,800 kt in 2014, while China generated 7,317 kt of e-waste in 2014, which can be well justified with the fact that China is the most populous country. It also receives the highest amount of e-waste imported from developing countries[31]. Table 1 also depicts the estimates calculated for year 2012 and 2005 which were obtained from literature review. The comparison between e-waste generations of different years illustrates the trend of e-waste

generation over a decade. Assuming these data reasonable, we can estimate that over a period of almost 9 years, e-waste generation has been doubled for South-East Asian countries.

2.2. Global regulations

The Basel Convention on the control of transboundary movements of hazardous wastes and their disposal (1989) is an international treaty which restricts the movement of hazardous waste between countries with emphasis on the movement of waste from developed nations to developing nations[32]. 181 countries are parties of the Basel convention while 53 are signatories[33]. The Basel Ban Amendment (1995) restricts all type of hazardous waste from transboundary movement for any reason, including recycling. Table 2 lists important legislation present worldwide which deals with the handling, import, and transboundary movement and management of e-waste. The Basel Convention is the mostly adopted convention worldwide, yet it has not been ratified by the US. Additionally, the Rotterdam Convention on the Prior Informed Consent Procedure for certain hazardous chemicals and pesticides in International Trade (1998) and the Stockholm Convention on persistent organic pollutants (2001) also address the movement of hazardous substances between countries. Other than these global agreements and regional initiatives, countries have their own domestic regulations and laws for e-waste and their transboundary movement.

3. E-waste in Pakistan

The problems associated with e-waste in Pakistan started evolving after the first phase of economic liberalization with an average GDP growth rate of 6.8% during the 1960s[34] [35]. Pakistan was seen as a model of economic development around the world[36]. Due to increasing population and purchasing capacity, there is currently an increasing demand for electronic goods industry in Pakistan, especially for home appliances (TV, refrigerator, washing machine, AC, ovens, etc.), telecommunication, IT, and computers. All major components in electrical equipment is imported

161 or smuggled and, only assembled in Pakistan which means entire electronics and electrical
162 appliances industry is running on imported parts[37]. The scenario illustrates that increasing sales
163 and importation of electronics will result in an increasing future generation of e-waste in Pakistan.
164 The rapidly increasing sales along with indigenous technological advancements, have led to
165 significant e-waste generation from households, organizations, industries and public sectors. Solid
166 waste management, which is already a mammoth task in Pakistan[38,39] has become even more
167 challenging by the invasion of e-waste generated domestically as well as imported from developed
168 countries.

169 **3.1. Scale of informal recycling**

170 Hazardous recycling operations are carried out in informal facilities in order to recover
171 valuables from e-waste. Recycling techniques like physical dismantling, open burning, acid bath,
172 and use of blow torches is practiced in open air as well as in small workshops in e-waste recycling
173 areas in Pakistan. Workers without any protective respiratory equipment or special clothing of any
174 kind dismantle all types of equipment (Figure S1). Main parts of the computer are separated and
175 then treated by employees according to the demand of scraper. Recovery of valuable metals as
176 copper, often from TVs and monitors, are the main interest while other parts of monitors are
177 dumped/burnt openly or sold at a very cheap price. The recycling of circuit boards is carried out
178 in a both primitive and hazardous way; circuit boards are heated first through blow torch to recover
179 the metal and melt the plastic, then the metal part is subject to acid, which separates different
180 metals as copper and gold are of most importance for scrapers. Informal recycling operations are
181 mostly carried out in small workshops with limited ventilation. The burning and melting of e-waste
182 represent a risk for labourers, which are exposed to toxic emissions from such activities. Workers
183 and people residing in vicinity of e-waste recycling areas are not well informed of the hazards

associated with informal recycling of e-waste. There is yet no regulatory authority to oversee the occupational exposures and pollution caused by the processing of e-waste in Pakistan. Workers appear to ignore the potential hazards as informal recycling of e-waste represents an important source of income.

3.2.Amounts (in Pakistan)

Pakistan ranks 6th in population among all the countries worldwide and is expected to be in 5th place till 2050, but is considered as a 3rd world country due to its still developing infrastructure and economy. Most people residing in Pakistan have a limited capability of purchasing new and advanced electrical items so they mostly buy second hand products. This situation creates a market demand for cheaper 2nd hand or end of life equipment to be imported into the country. Negligence of governmental bodies and legislative organizations has led to a situation in which Pakistan has no inventory on the domestic generation of e-waste nor the illegal import of 2nd hand equipment or e-waste.

3.2.1. Domestic generation

In 2013, the highest retail and purchasing power was recorded for Pakistan which also translates into increased use of electronics[40]. In April 2014, the country's total mobile phone subscriptions were recorded to be all time high of 137.68 million, which also indicates the high consumption of mobile phones which will eventually increase the amount of e-waste generated[41]. Purchasing of TVs and monitors are also forecasted to increase at annual growth rate of 12% due to rapid replacement of technologies[42]. The market for PCs continues to increase because of increasing demand from consumers, enterprises and the public sector. Computer sales increased from 409mn $ in 2014 to 432mn $ in 2015 with 5.8% annual increase in sales and cell phone sales recorded an annual increase of 9.1%[42]. Rapid urbanization is also a major drive for increased

consumption, as people become introduced to newer technologies and are attracted to buy the products. The increased consumption will eventually lead to higher amounts of domestic e-waste generated.

Table 3 presents the estimated generation of e-waste in Pakistan for the year 2012, according to 'Step" [21]. Using the information from "Step" as a reference, the amount of e-waste in Pakistan is estimated for the year 2014, and is calculated as 316 kt approximately while UNU estimated it to be 266 kt with 1.4 kg per individual in 2014[20]. These estimates, which are in fair agreement, are both higher than historical estimates; Breivik et al.,[22] estimated that Pakistan generated approximately 210 kt of e-waste in year 2005 which was estimated by distributing the global e-waste generated to individual countries using GDP as a surrogate[23]. Assuming these estimates are reasonable, this implies that the e-waste generation in Pakistan may have increased by up to about 50% over the last decade. Although the data reflect domestic generation and do not include illegal imports, it indicates an increasing trend for domestic e-waste generation in Pakistan.

3.2.2. Future development (GDP)

As the world is globalizing, newer technologies are evolving which will affect the global generation of e-waste. Any country's gross domestic product (GDP) strongly affects the generation of e-waste, as electrical and electronic equipment are essentials of a growing economy[22]. To predict the future generation of e-waste in Pakistan, we used GDP (PPP) which can be indicative of purchasing power of per capita, and would give us an idea of domestic e-waste generation. This approach is practiced frequently for estimation of e-waste generation globally as well as country wise[43,23]. Increasing GDP (PPP) of a country would be an indicative of increasing purchase of electronics and thus increased generation of e-waste.

229 According to World Bank, Pakistan had a GDP (PPP) of 4602 US $ per capita for the year
230 2013. Hischier et al.,[43] reported that the annual growth of e-waste in EU is increasing at a rate of
231 3–5%, compared to an average (2005–2008) increase in GDP of 2.6%[44]. Pakistan had an annual
232 increase of 2.7% GDP per capita in the year 2013 and population growth rate is 1.6%[45] which
233 combined leads to an anticipated increase in domestic e-waste generation. While keeping in mind
234 the Step e-waste generation data for Pakistan, we calculate an increase of 5.5% in the e-waste
235 generation in Pakistan from 2012 to 2014, comparable to the situation in EU. Statistics supports
236 the idea that Pakistan will be one of the leading countries in e-waste generation with a population
237 of 234 Million and 5277 US $ GDP (PPP) per capita in the year 2050[46] (Fig. 2). While considering
238 the estimated figure of ~50% increase in e-waste generation during the last 10 years (Table 1), we
239 can foresee that the future generation of e-waste is going to increase in Pakistan. These stockpiles
240 of e-waste generated domestically along with the imports will create a complex scenario for e-
241 waste management in Pakistan.

242 Another important consideration is the changing nature of e-waste and penetration of cheap
243 electronics due to technological advances in electronics and electrical appliances industries. Also,
244 these events will precipitate the disposal of large quantities of obsolete electrical and electronic
245 equipment. The average life span of computers, TVs, cell phones and other electrical devices are
246 dropping as technology is advancing. For example, the average lifespan of central processing units
247 in computers dropped from 4–6 years in 1997 to 2 years in 2005[47]. We can also expect the material
248 composition of e-waste to continue to evolve as manufacturers opt for cheaper, accessible and
249 more efficient raw materials[22].

250 **3.2.3. Import from aboard**

Pakistan still lacks the appropriate technology and expertise to establish a viable industrial base in the electronics sector and majorly relies on imports of EEE. According to World Bank data IT imports accounted for 3.8% of total goods imported in 2013. Since lifting of GST exemption in 2005, increased import of used PC/scrap and undocumented import has been noticed[48]. The 3.8% is the official or legal figure for imports while as per some estimates 50% of PC products are smuggled or brought in through illegal means[49]. No accurate official data or estimates of EEE imports into Pakistan have been presented yet. Along with domestically generated e-waste, imports also represent a fraction of net e-waste produced in Pakistan. Most of the e-waste imported to Pakistan is still in category of unknown imports, which are not documented by customs department. Yearly import data of 2014 for old and used computers from the customs department was accessed which was received from known sources and had known quantities[50]. All of the computers imported were old and used which were in following order with respect of most imports; US> UK> Canada> UAE> Singapore> Australia> Spain> China> Korea. A total of 70-80% of the imports was from US while 10-15% was from UK and 5% from other countries. The data from the customs department provides evidence that e-waste is actually being imported into Pakistan from countries camouflaged as second hand or used items.

Calculations were performed to estimate the amount of computers imported in 2014. The number of computers was converted to weight by multiplying it with 25kg which is the constant weight taken for old computers and calculation showed that approximately 12.46kt old computers are imported from various countries into Pakistan through Karachi seaport[50]. IT and telecommunication equipment accounts for 16.3% of total e-waste generated in EU by weight[43], so if we assume that there is some similarity between Pakistan and EU then by calculating the total generation of computer e-waste we can estimate the contribution of imported e-waste to total

computer e-waste generated. For this we will firstly, calculate the contribution of imported computers to the total e-waste generation in Pakistan and secondly, we will then calculate the contribution of imported computer e-waste to total computer e-waste generation. For the calculation of contribution of an item to total e-waste stream, we used (1);

$$E = \frac{MN}{L} \quad (1)$$

The mass of imported computers is used as M (25kg) while N (498378) numbers of computer were imported in 2014 to Pakistan. Here we took average computer weight as 25 kg and average life span (L) as 3 years[51]. The purpose of taking 25kg as average weight is that all of the computers imported were old and used which were possibly of old manufacturing design. By putting the values in above expression we get 4.15kt/year, which is the contribution of old and used imported computers for year 2014 to total e-waste stream generated in Pakistan.

After obtaining the value of 4.15kt/year, we proceed to the second step of our calculation which will give us a resulted contribution of imported computers to the total computer e-waste generated in Pakistan. By assuming the same situation for EU and Pakistan, we take 16% as an approximate figure which represents the fraction of IT and communication equipment of total e-waste generated. By dividing (4%/16%), we get 25% which is the estimated contribution from import of used computers from various OECD countries to the total generation of computer e-waste in Pakistan. This estimate might be biased low because IT and communication equipment in WEEE directive is more than computers.

Although data are scarce, it provides an initial estimate of the extent to which e-waste imported from developing countries is contributing to the total e-waste generated and also which country is most contributing in terms of exporting e-waste to Pakistan. Computers with an average lifespan

296 of three years comprise a greater proportion of e-waste stream in terms of number than most of the
297 home appliances (refrigerators, ovens, washing machines) which have lifespan of 10–12 years[22].
298 And also technology advancement may be faster for computers and cell phones rather than home
299 appliances. Keeping in mind, this data only represents a single product group of imported e-waste;
300 much is needed to be explored as there is also a hidden or illegal import of other forms of e-waste
301 into Pakistan from OECD nations which could be in larger quantities than these known figures[30] .

302 **3.3. Flows and destinations of e-waste within Pakistan**

303 **3.3.1. E-waste flows**

304 Figure 3 shows a simplified flow chart for electronic and electrical equipment from sources to
305 e-waste. In Pakistan, e-waste is generated from three key sources; domestic manufacturing,
306 domestic consumption and import. After disposal, e-waste is collected by scrapers and vendors,
307 who sometimes dismantle the waste in several parts which is, in turn, sold to extractors and
308 dismantlers. Extractors and dismantlers by using illegal means then treat the waste to extract
309 precious and valuable materials and discarded waste is then often disposed of either in landfills or
310 water bodies (Fig. S1 a,b,c). Sometimes scrapers and dismantlers reassemble different parts of old
311 equipment for resale. Laborers may not be fully aware of the potentially harmful consequences of
312 recycling or dismantling electronics, thus exposing themselves to high toxicity[52]. Crude recycling
313 techniques are adopted like physical dismantling, open burning, acid bath, and use of blow torches
314 to extract valuable metals, as all these procedures are very cost efficient (Fig. S1 b, c). The scale
315 of informal recycling is growing day by day in Pakistan and is expanded in all over the country as
316 large and small scale business[53]. Up till now, there is no formal e-waste recycling facility available
317 in Pakistan; all the e-waste is recycled through illegal and/or informal means.

318 **3.3.2. Major e-waste areas**

As discussed in the above section, electronic and electrical waste is imported and labelled as 'second-hand equipment'[54]. A very small amount of the imported material is reusable, and after the removal of these usable items, the bulk of that shipment is sent to recycling industry[24]. The major recycling waste sites in Pakistan are located in the city of Karachi. Lahore, Faisalabad, Peshawar, Gujranwala and Islamabad/Rawalpindi are also involved in the recycling and dismantling of the e-waste, but at a very small scale compared to Karachi (Fig. S2). Karachi, being a sea port, receives the containers of e-waste from all around the world. After clearance from the port, this waste is sent to ware houses from where scrapers buy the items by weight. E-waste is dismantled, burned or dumped depending on its composition. Hundreds of workers including teenage children earn their livelihood by dismantling and extraction of valuable items from the e-waste[52].

Karachi is situated in the southern part of the Pakistan and it is the largest business hub of country with the highest population estimated to be 15 million. Rapid industrialization leads to urbanization of the city, which resulted in the altered environment and ecological disturbances in the city[55]. Lyari is the largest dumpsite in Karachi for e-waste along with Sher Shah, Jacob lines and Surjani town. When the waste is recycled or dismantled, the later bulk of waste is either landfilled or trashed into the Lyari River, which is flowing by the side of Lyari district[54]. The River passes through the mangroves, and then finding its way into the Arabian Sea. Mangroves are the natural filters of the ecosystem, but studies show that the mangroves of Indus Delta are highly polluted with metals[55].

Lahore is the second largest and metropolitan city of Pakistan after Karachi. Due to attractive business opportunities, the population of city is constantly increasing which has also led to extreme air, water and soil pollution in the city[56]. E-waste is one of the major problems which are in dire

need to be elucidated by the Governmental authorities. Major markets of e-waste are Hafeez Center, Hall Road, Beadon Road, Misri Shah, Mayo Hospital and Pakistan Mint (GT Road) in the Lahore city. E-waste is recycled and valuables are extracted in non-ventilated rooms in these areas, which cause potential serious health effects to the workers. Recently City district Government Lahore, a provincial body had shut down some 25 factories which were involved in the burning of batteries, containing lead and cadmium[57]. Air quality around the areas dealing in e-waste material and recycling is significantly degraded[58].

Rawalpindi being situated adjacent to the capital Islamabad, is one of the major cities of Pakistan. In Rawalpindi e-waste recycling and dismantling is at very small level as compared to Lahore and Karachi. The main area which deals with the scrap and 2nd hand electronics is College road situated near Raja Bazaar which is the main business market in the city. Many workers that were employed in the ware houses were reported to be suffering from Asthma[52]. Small children were also found to be employed for the cleaning, dismantling and burning of the circuit boards and other items[52].

3.3.3. Domestic regulations on e-waste in Pakistan

The amount of e-waste generated is going to increase in the future; [8]still there is no homework done on the management of waste produced every year. Growing problem of e-waste in Pakistan clearly requires a more effective legislation which explicitly deals with e-waste. Pakistan environmental protection act (PEPA) came into force in December, 1997. Section 11 of this act prohibits discharge or emission of any hazardous chemical in the environment and Section 13 strictly prohibits the importation of any hazardous substance in the territory of Pakistan[59]. Import Policy order 2007-08 restricts the import of any material that is mentioned in the Basel Convention, it also clearly indicates that air conditioners, refrigerators and other home appliances in used or

second hand condition are not allowed to be imported[60]. Trade policy 2006-07 addresses the same as import policy emphasizing on restriction of import of hazardous waste as described in the Basel Convention.

These regulations have guided and given basic constraints on e-waste management, but on the other side it can also be observed that these legislations have described the key elements and principles very generally which restrict their empowerment and implementation. Although Pakistan is signatory of the Basel Convention, import of waste which comes under the label of reusable or recyclable products, which continues[24]. The situation of informal recycling can be improved if the Government frames special laws to regulate it and facilitate the ones which are directed towards more formal recycling of e-waste. Not only can this be beneficial for the people involved in this business but also it will generate revenue for Government as Pakistan is importing tons of e-waste every year.

3.4. Data gaps and research needs

A sounder domestic e-waste management system in developing countries like Pakistan will require several elements including, but not limited to, a national registry/inventory, a more formal collection system as well as logistics. Pakistan is way behind in all these three elements. Furthermore, there are major data gaps and research needs required to better inform and support future e-waste management in Pakistan, some of them which are discussed in the following paragraphs. In this context, Pakistan may benefit from the experiences made both in other developing countries with similar conditions as well as developed regions in terms of future research and management strategies.

i. A national registry keeping track of produced electronics is in a nascent stage in China and India. According to Abbas (2010), such inventorying is essentially not done in Pakistan[61].

Quantitative inventories of quantities of products and e-waste being imported, manufactured, consumed, recycled and dumped in landfills or water bodies are basic activity data which need to be developed and maintained by regulatory authorities for future assessment. India has set up and run trials on an inventory system during the past decade[62] while China has committed to make an e-waste inventory with its new e-waste law (2011), containing data on electronic items domestically produced in China[6]. As UNEP says, that China has a great potential for handling e-waste and can be seen as large scale handler of e-waste [63], Pakistan can take China as an example for managing e-waste.

ii. To minimize future environmental pollution from the handling of e-waste, inappropriate handling and informal recycling, such as open burning must be addressed and mitigated. Open burning, especially of wires and cables, may release a wide range of persistent organic pollutants and heavy metals (Fig. S1a) [64,65,66]. There may be resulting health effects from these pollutants. Till now there is no single study reported from Pakistan which have been addressing the potential impacts and health effects caused by pollution from informal e-waste recycling[61]. There are a lot of studies reporting pollution and health effects due to e-waste recycling in developing [67,68]as well as developed countries[69] which could serve as a basis for future research into these issues in Pakistan. A particularly worrisome feature is that recycling scrapers employ child labourers aged 8 to 18, who work in the absence of any protective gear like goggles, mask or gloves[61].

iii. Pakistan has been recognised as one of the major destinations for e-waste imports in Asia [24,23]. The lack of reliable and quantitative data on illegal e-waste imports is recognized as a key knowledge gap in Pakistan. However, quantifying the extent and trends of such imports is notoriously difficult because such imports are often masked using misleading or

false declarations, such as ”second-hand goods” or by mixing e-waste with legitimate consignment[3]. Identifying the extent and major routes of imports into Pakistan is another important knowledge gap, which needs to be minimized to offer a more nuanced and balanced perspective.

iv. There is also a critical need to develop and implement more eco-friendly recycling strategies in Pakistan for recovery of valuable metals and other raw materials from e-waste. In this case, Pakistan may benefit from the experience and technologies in developed regions. Switzerland is the first country in the world to have established a formal system to manage e-waste[70]. Swiss system imposes high safety and emission standards and stresses the implementation of regular controls and monitoring at every stage of e-waste management system[70], which led to minimized environmental contamination.

v. Identifying e-waste recycling sites is another important consideration that needs to be addressed by authorities. Few locations are identified by reliable sources as e-waste recycling hubs in Pakistan, some of which are discussed in this study. It is anticipated that there are many more informal recycling sites, especially in and around Karachi city and urbanized centres of Punjab province.

vi. We conclude there is a critical need for a more comprehensive understanding of the current situation in Pakistan with regard to potential harmful effects on environmental and human health originating from various e-waste activities which, in turn, is likely to identify further research needs. Our preliminary findings indicate that e-waste is an emerging issue, which needs to be monitored well into the future, if nothing else because of increased domestic consumption of electrical and electronic equipment in Pakistan in the years to come.

3.5. What can be done to avoid e-waste problem in Pakistan?

Pakistan is facing an emerging problem due to increasing amounts of e-waste, seemingly with limited policies and regulation to effectively mitigate this problem. More accurate data on the scale of e-waste imported, manufactured or consumed in Pakistan is urgently needed. There is also a lack of accurate information how much of e-waste is dumped and how much is recycled. With the ban on imports of e-waste in China and India, it is a risk that the import of e-waste into Pakistan may increase[71]. To avoid a possible worsening of this situation in Pakistan, actions need to be taken at governmental as well as individual levels. Increased attention and strengthened efforts from the government are needed to mitigate illegal imports and informal recycling of e-waste in Pakistan. Key actions that the government needs to take to face the emerging challenges of e-waste are briefly discussed below;

i. **Regulatory measures**: To start with, the government of Pakistan first needs to enforce the rules that already exist, such as the Basel Convention, which restricts the import and trans-boundary movement of hazardous substances, becomes more effective. Apart from existing laws and regulations, government shall devise e-waste specific national level legislation. The legislation should be in line with the issues addressing recycling and disposal/management of e-waste in Pakistan. The legislation should take cognizance of the following items;

    a. The establishment of standards and a certification system for second hand appliances, and recycling and disposal enterprises to ensure safety and the environmentally sound processing of e-waste and emphasize on establishment of formal recycling facilities.
    b. Encourage importation and consumption of EEE that complies with the international regulations (Basel convention, EU directive on WEEE)
    c. Encourage the development of relevant and/or best available technology for e-waste management.

d. Make provisions for the adequate funding of e-waste collection, storage, and environmental friendly recycling and/or disposal

e. Introduce measures for the establishment of formal e-waste recycling and disposal facilities.

f. Requirement for producers to provide information on the components and hazardous substances present in their products, as well as on safe use and recycling and encourage the use of "green technology".

Apart from that, Government shall draft separate legislations addressing e-waste management and technical policy for prevention of pollution from e-waste.

ii. Economic assistance: E-waste contains valuable as well as hazardous substances. The unregulated and informal recycling of e-waste only recovers the most valuable and easily extractable materials like copper wiring, lead soldering and gold plating. Other difficult to extract or less valuable components such as toner cartridges, desoldered printed wiring boards, and plastic bodies are often discarded or openly burnt. This could be taken as a waste of useful resources. If treated properly this waste can generate jobs as well as conserve natural resources. Establishing formal recycling facilities will provide income generating opportunities for both individual workers as well as small scale enterprises, as waste is traded among collectors, scrapers, second-hand dealers, consumers and processors.

The financial benefits of formal e-waste recycling are in stark contrast to dumping e-waste in landfills or incinerating e-waste. Such methods employ only a few people and, far from generating income, lead to many unproductive expenses such as transportation costs, indirect health costs and the like. Recycling e-waste properly will not only create jobs but it

will also help recover raw material which can be incorporated in refurbished and recycled EEE thus saving cost for manufacturing new products.

iii. **Technological improvements:** Pakistan still lacks appropriate technology and expertise to establish a viable industrial base in electronics sector, as only 3% is contributed by the sector[72]. Pakistan majorly relies on imported spare parts of electronics which are later assembled locally while some companies have initiated the domestic production very recently. E-waste problem can be avoided if we provide technical assistance to local manufacturers and importers of electronics spare parts. Use of renewable and eco-friendly products shall be encouraged and electronic devices should be designed to ensure clean, safe and environmentally sound recycling. Focus should be given to green product design, green product labels, encouragement of research and development of technology and equipment and the formulation of associated national policies and standards. Recycling and refurbishment industries should be strengthened by collaborating with international companies.

Pakistan's Government may also introduce further take back systems reflecting the experience from other nations. End user has to pay a recycling fee and recycling is executed by the manufacturing company of that specific product, which results in recycling of all e-waste generated. Extended Producer Responsibility (EPR) is defined as an environmental protection strategy that makes the manufacturer of the product responsible for the entire life cycle of the product and especially for the take back, recycling and final disposal of the product[73,74]. Thus, the producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle[75]. This initiative would help not only to reduce informal recycling of e-waste, but also facilitate awareness among public consumers in Pakistan. Many manufacturers and producers of electronics and electrical equipment offer take-back systems,

even if it is not mandated by law. Nokia introduced a take-back campaign in Pakistan in 2010 which created awareness in public [61], which was abandoned later for unknown reasons. Apart from take back systems, there should be an introduction of more formal collection and recycling systems of e-waste. Formal and well equipped recycling centers should be established to recycle e-waste at the lowest possible expense of environment and human health. Formal recycling centers should also develop mechanisms and logistics for transportation and collection of the waste. If this business of recycling is formalized and legalized and equipped with technological advancements, Pakistan can potentially benefit also in financial terms through increased recovery of valuable metals and raw materials, jobs and by minimizing the potential for detrimental health effects on labourers and on the environment.

iv. **Public awareness:** The first and foremost important solution to the e-waste crisis is to eliminate hazardous chemicals from the equipment and to save the general public and workers from the emissions resulting from recycling of e-waste. Before that happens, recyclers, manufacturers, scrapers and general public must be educated regarding the potential threat to public health and environment posed by e-waste, and awareness must be raised for waste management protocols. Workers involved in waste processing activities must be properly trained and educated with occupational health and safety. TV advertisements and newspaper articles may also help in creating awareness in general public about hazards of e-waste as well as need for eco-friendly recycling to conserve natural resources and sustainable use of available resources.

To sum up, our review of the situation in Pakistan reveals that it is not yet prepared to face and manage the challenges ahead, attributed to the increasing amounts of e-waste and their potential harmful effects on environmental and human health. It is therefore a critical need for further

research into these issues in Pakistan to obtain a more holistic and nuanced perspective on relevant issues, and to further compare and contrast the situation in Pakistan versus other countries. As pointed out earlier, a strengthened research effort into these issues in Pakistan could significantly build upon and benefit from international collaboration, reflecting the experience and knowledge base already established from studies in other developing regions and emerging economies, such as China and India. A similar reasoning applies to the need for enforcement of both strengthened policies as well as implementation of more formal recycling technologies. Clearly, a better knowledge base through intensified research efforts is anyhow essential to support the government, the public and relevant stakeholders, to agree upon sound control strategies in the future to better manage the increasing e-waste problem in Pakistan.

- **Associated contents**

Supporting Information

Supplementary information contains two supporting Tables and two Figures.

- **Acknowledgments**

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- **Conflict of interest**

The authors declare no competing financial interest.

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Emerging issue of e-waste in Pakistan: A review of status, research needs and data gaps

Mehreen Iqbal[a], Knut Breivik[b,c], Jabir Hussain Syed[d*], Riffat Naseem Malik[a], Jun Li[d], Gan Zhang[d], Kevin C. Jones[e]

Figures

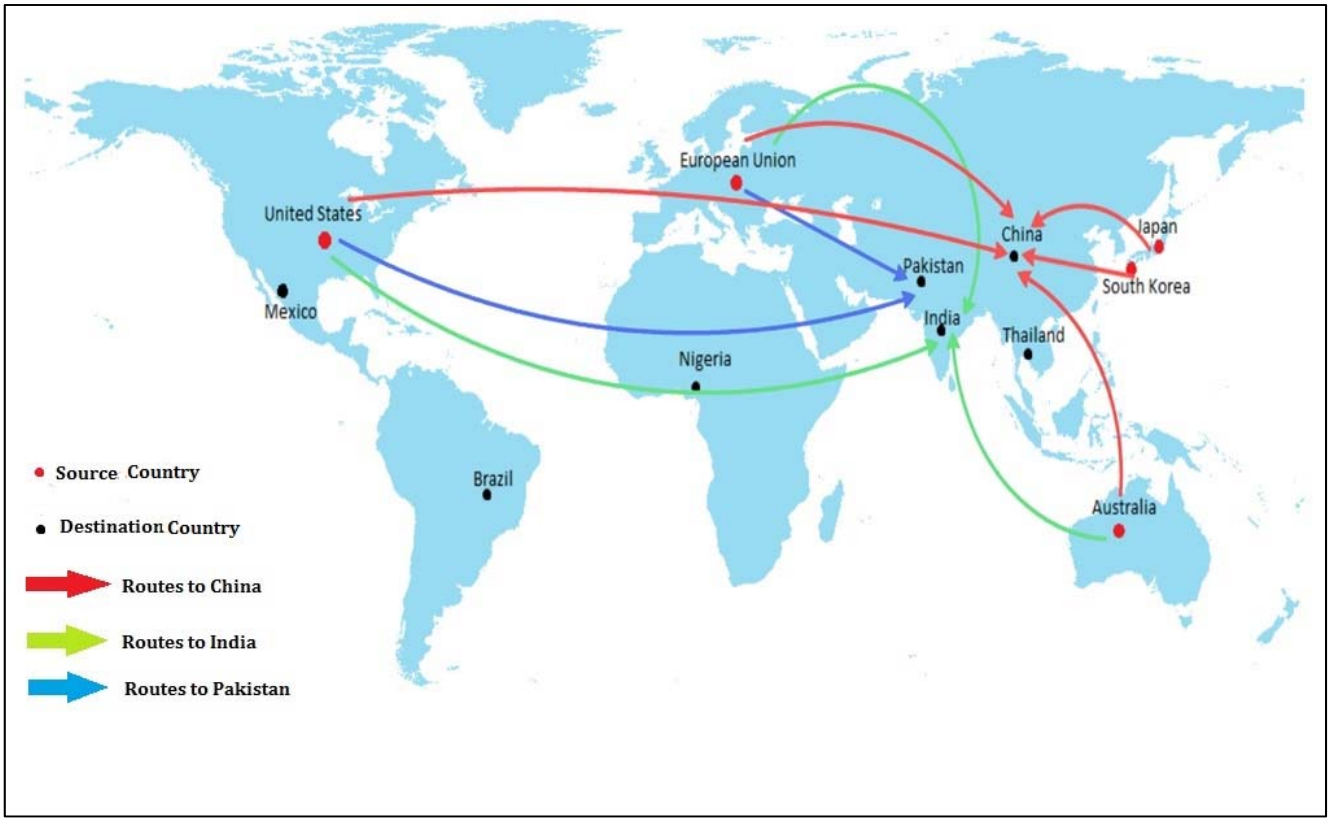

Figure 1: Hidden flow of e-waste from developed countries to developing Asian countries[1234]

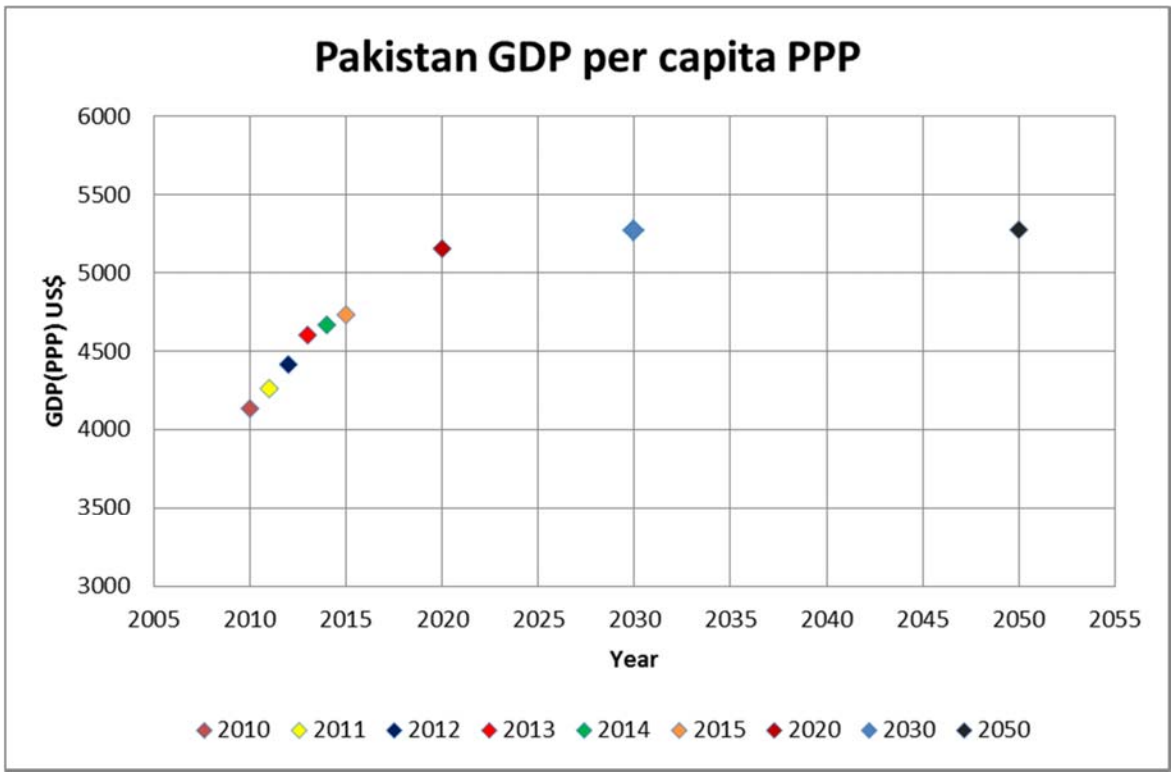

Figure 2: Pakistan GDP per capita PPP comparison of present and predicted values (Economies, T. Forecasts. http://www.tradingeconomics.com/forecasts)

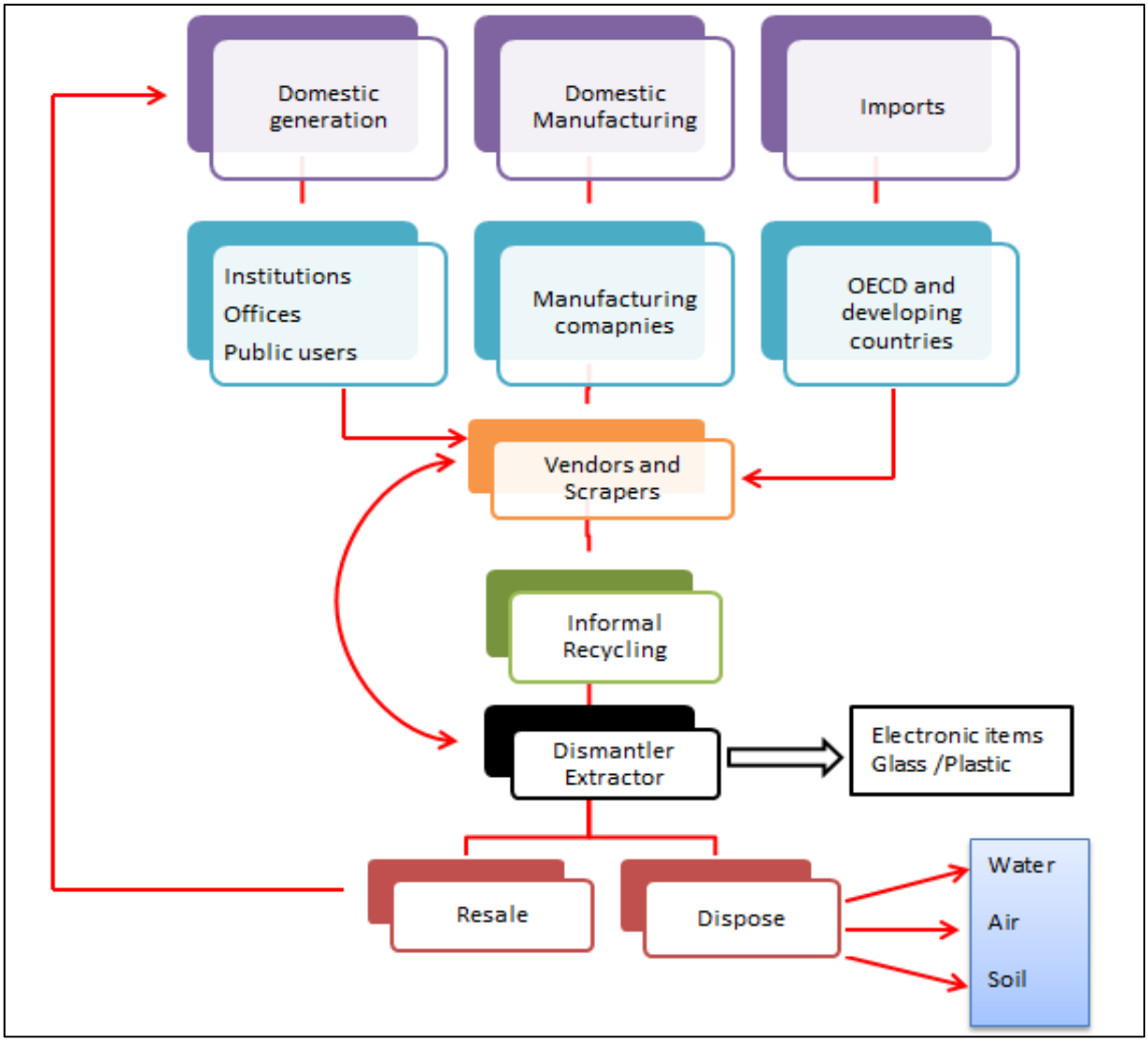

Figure 3: Flow chart showing fate and transport of electrical and electronic equipment in Pakistan along with major sources of e-waste (consumption, manufacturing and importation)

Emerging issue of e-waste in Pakistan: A review of status, research needs and data gaps

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Tables

Table 1: Comparison of e-waste generation in major Asian countriesError! Bookmark not defined.

Country	E Waste Generated Per Inhabitant/Kg (2012)	E Waste Generated Total In Metric Kilotons (kt)		
		2005	2012	2015 (Present Study)
China	5.36	3300	7253	7317
India	2.25	1600	2751	2803
Pakistan	1.68	210	300	315
Global	---	35000	48894	---

Initiative U.N. U.S., 2012; Breivik et al., 2014

Table 2: National and International regulations addressing e-waste

The Pakistan Environmental Protection Act 1997	Section 13 prohibits the import of hazardous waste and Section 14 disallows handling of hazardous elements
Trade Policy - 2006-07, Government of Pakistan	Policy states that Hazardous wastes as defined and classified in the Basel Convention cannot be imported
Basel Convention	Adopted on 22 March 1989 in Basel, Switzerland. The Convention entered into force in 1992 to restrict the trans boundary movements of hazardous waste. 172 countries are signatory, but does not ratified by US.
Bamako Convention	It is a treaty of African nations, which restricts the import or trans boundary movement of any type of hazardous waste within African countries. It came into force in 1998 with 30 signatory nations.
EU WEEE Directive	Adapted by all EU nations by 2007. The directive set recycling, collection and recovery targets for 10 categories of electrical items.
Restriction of Hazardous Substances Directive (RoHS)	Came into force in 2003, implemented with WEEE directive in 2006, restricts the use of Pb, Hg, Cd, PBB and PBDE in the production of electrical and electronic goods, adapted by many other countries including China and India.
E-Waste Association of South Africa (eWASA)	Established in 2008 to manage the establishment of a sustainable environmentally sound e-waste management system for the country
The export and import of hazardous waste and hazardous recyclable material regulations (EIHWHRMR), Canada	It prohibits hazardous waste from being imported or conveyed in transit
California Electronic Waste Recycling Act	Law to reduce the use of certain hazardous substances in certain electronic products sold in the state. The act was signed into law September 2003
E-Stewards Initiative	It was developed by the Basel Action Network in 2002, it is an industry-specific environmental management system standard

Sthiannopkao et al., 2013

Table 3: Overview of e-waste related information from Pakistan

Subject	Unit	2005	2012 [2]	2015 (Present study)
Population	(total inhabitants in million)	-	179	185
Purchasing Power	(USD per Inhabitant)	-	2876	-
EEE Put on Market	(kg per inhabitant)	-	2.68	-
	(total in metric kilotonnes)	-	479	-
E-waste Generated	(kg per inhabitant)	-	1.68	-
	(total in metric kilotonnes)	210	300	317

Bhains et al., 2006; Robinson et al., 2009

Supplementary Information

Emerging issue of e-waste in Pakistan: A review of status, research needs and data gaps

Mehreen Iqbal[a], Knut Breivik[b,c], Jabir Hussain Syed[d*], Riffat Naseem Malik[a], Jun Li[d], Gan Zhang[d], Kevin C. Jones[e]

Table S1: WEEE categories according to the EU directive on WEEE (EU, 2002a) [1]

S. No.	Category	Label
1	Large household appliances	Large HH
2	Small household appliances	Small HH
3	IT and telecommunication equipment	ICT
4	Consumer equipment	CE
5	Lightning equipment	Lightning
6	Electrical and electronic tools (with the exception of large-scale stationary industrial tools)	E & E tools
7	Toys, leisure and sports equipment	Toys
8	Medical devices (with the exception of all implanted and infected products)	Medical equipment
9	Monitoring and control instruments	M & C
10	Automatic dispensers	Dispensers

Table S2: Potential Environmental Contaminants and their Concentrations Released during Recycling and Disposal of e-waste[2]

Contaminant Classes	Relation with e-waste	Typical e-waste conc. (mg/kg)	Annual global emission (tons)
Polybrominated diphenyl ethers (PBDEs) polybrominated biphenyls (PBBs) tetrabromobisphenol-A (TBBPA)	Flame retardants	--	--
Polychlorinated biphenyls (PCB)	Condensers, transformers	14	280
Polycyclic aromatic hydrocarbons (PAHs)	Product of combustion		
Lead (Pb)	Solder , CRTs, batteries	29,00	58,000
Chromium (Cr)	Data tapes, Floppy Discs	9900	198000
Copper (Cu)	Wiring	41,000	820,000
Antimony	Flame retardants, Plastics	1700	34,000
Nickel (Ni)	Batteries	10,300	206,000
Zinc	--	5100	102,000

Figure S1 (a): Open burning of wires to retrieve metal in Shershah, Karachi (Liyari river can be seen at the back which is ultimate dumping site for all types of waste) (Photo: Giovanni Porzio)

Figure S1(b): Labourer performing physical dismantling of electronics without protective gear, Karachi (Photo: Giovanni Porzio)

Figure S1 (c): Extraction of valuable materials through blow torches and physical disintegration, Karachi (Photo: Giovanni Porzio)

Figure S2: Major localities of e-waste dismantling and recycling sites in Pakistan

References

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